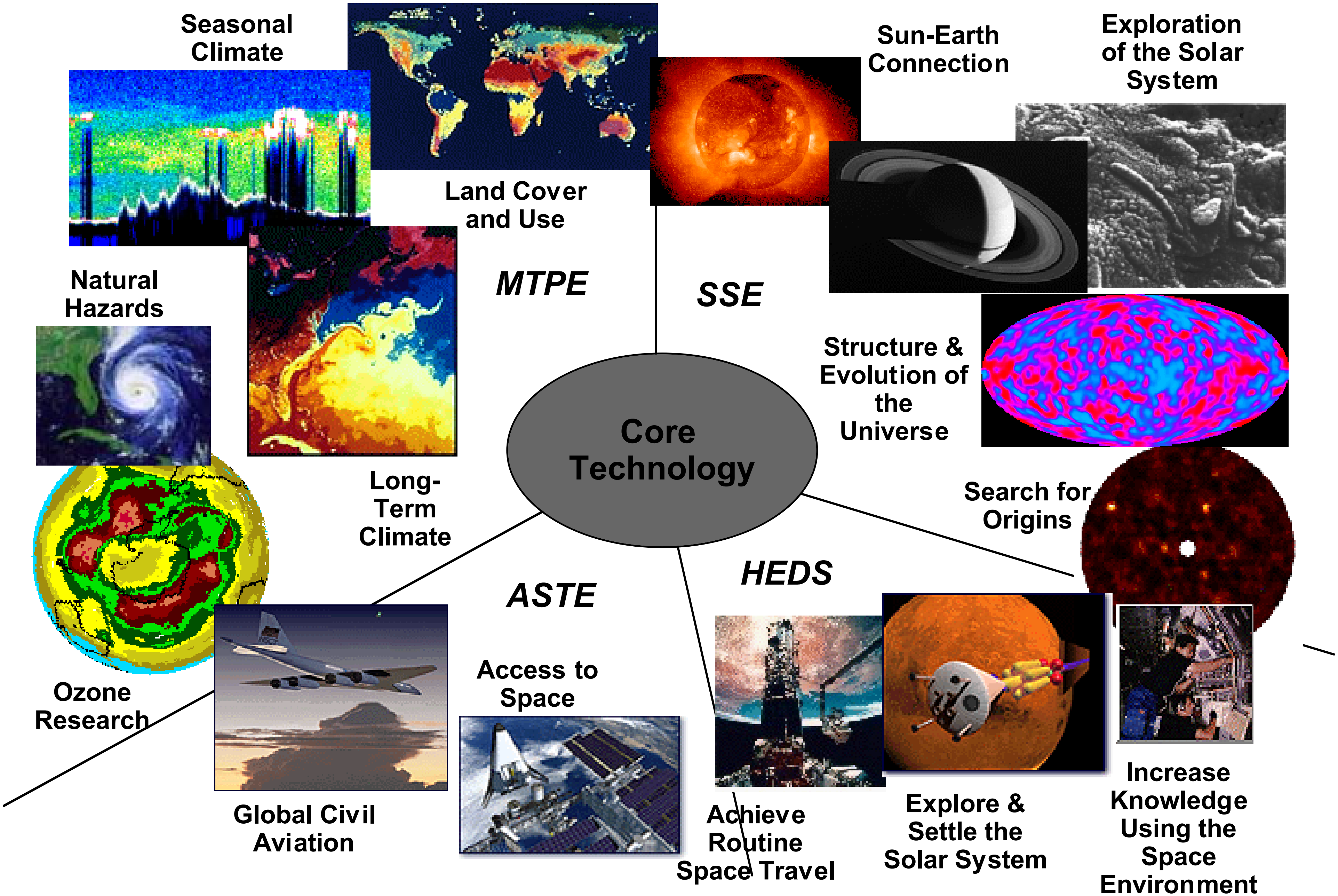
Cross Enterprise Technology Development Program

Where We Are and Where We Want to Go

C.R. Weisbin and G. Rodriguez

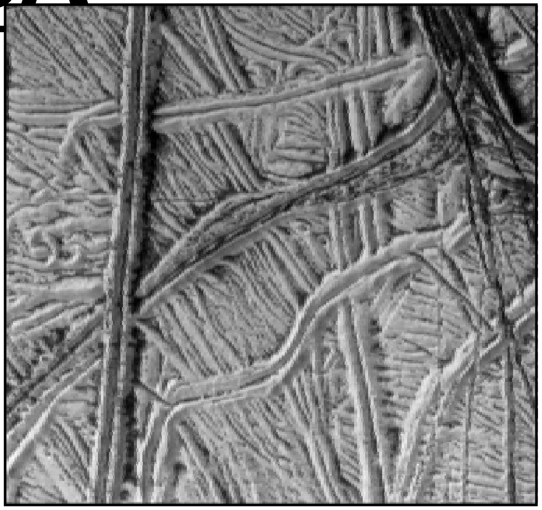
July 7, 1999

NASA Enterprise Themes



Grand Challenges for NASA

IMAGE AND STUDY
PLANETS AROUND
OTHER STARS

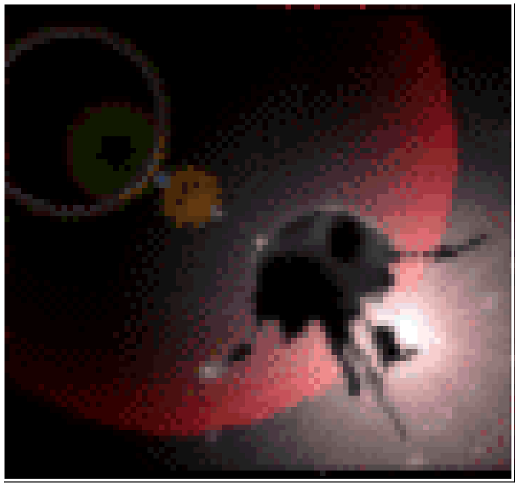


LOOK FOR EVIDENCE OF
LIFE ELSEWHERE IN THE
SOLAR SYSTEM

CONDUCT A PROGRESSIVE AND
SYSTEMATIC PLAN OF HUMAN
EXPLORATION BEYOND
EARTH ORBIT

READ THE HISTORY
AND DESTINY OF THE
SOLAR SYSTEM

SEND SPACECRAFT
TO A NEARBY
STAR



CETDP Program Basics

- CETDP (UPN 632)
  - FY1999 budget in 10 thrust areas ~ $100M
  - Major component of NASA's long term spacecraft technology activities

- Focus on low level, emerging technologies that will have a broad impact across the agency
  - Amortize NASA investment in leading edge technologies by spreading benefits and infrastructure across Enterprises
  - Leverage developments across Enterprises and other government agencies

CETDP Organization

Peter Ulrich, Head
OSS Advanced Technology & MIssion Studies
M. Montemerlo, CETDP Prog. Exec.

Gary Martin (GSFC)
CETDP Formulation Office

Steve Prusha (JPL)
CETDP Implementation Office

- **James Bagwell (GRC)** — High Rate Data Delivery
- **Peter Norvig (ARC)** — Thinking Systems
- **Chuck Weisbin (JPL)** — Surface Systems
- **Joe Sovie (GRC)** — Advanced Power & Propulsion
- **Tim Krabach (JPL)** — Breakthrough Sensors & Instrument Components
- **Kate Hartman (GSFC)** — Distributed Spacecraft
- **Chris Moore (LaRC)** — Ultra Lightweight Structures & Space Observatories
- **Jerry Housner (LaRC)** — Next Generation Infrastructure
- **Jack Stocky (JPL)** — Micro Nano Sciencecraft
- **Tri Nguyen (JSC)** — Atmospheric Systems & In Space Operations

Our Customer Long Range Challenges are Our Challenges

SPACE SCIENCE

ORIGINS: Precision, ultra-light optics; very large diffraction-limited telescopes

STRUCTURE & EVOLUTION OF THE UNIVERSE: Large ultra light/stable observatories; high-precision formations for VLBI; measure cosmic radiation from faint astronomical sources

SOLAR SYSTEM EXPLORATION: Robust economical colonies of intelligent robots for planetary exploration

SUN EARTH CONNECTION: Solar sails; constellations of autonomous miniature S/C enabled by innovative instruments

EARTH SCIENCE

ADVANCED SENSORS : Discover new events and interactions from unique vantage points of space, aircraft, and in situ platforms

SENSOR WEBS: Respond quickly, intelligently and cost effectively to events in the Earth system

ACCESS TO KNOWLEDGE: Information system architectures for easy access to global information for science, education, and applications

INFORMATION SYNTHESIS: Integrated architectures, to cut cost, and support productive, economical and timely missions

HEDS

OPERATIONS: Enable autonomous operations in support of humans in Space

SCIENCE RESEARCH: Extend scientific discovery and expand scientific knowledge

EXPLORATION: Enable affordable and robust human exploration beyond LEO

HUMAN LIFE SCIENCE: Enable humans to live and work permanently in space

Revolutionary Technology That Has Been Accepted that Does Not Exist

Revolutionary Technology That Has Not As Yet Been Accepted

Cross-Enterprise Technology Development Program Thrusts

- Ultra-Lightweight Structures & Observatories
- Surface Systems
- Breakthrough Sensors
- Thinking Space Systems
- Next Generation Infrastructure
- Power & Advanced Propulsion
- High Rate Data Delivery
- Micro/Nano Spacecraft
- In-Space & Atmospheric Systems
- Thinking Systems

The CETDP Program Develops Two Types of Revolutionary Technology in the Service of NASA and the Enterprises

We develop exciting revolutionary technologies which

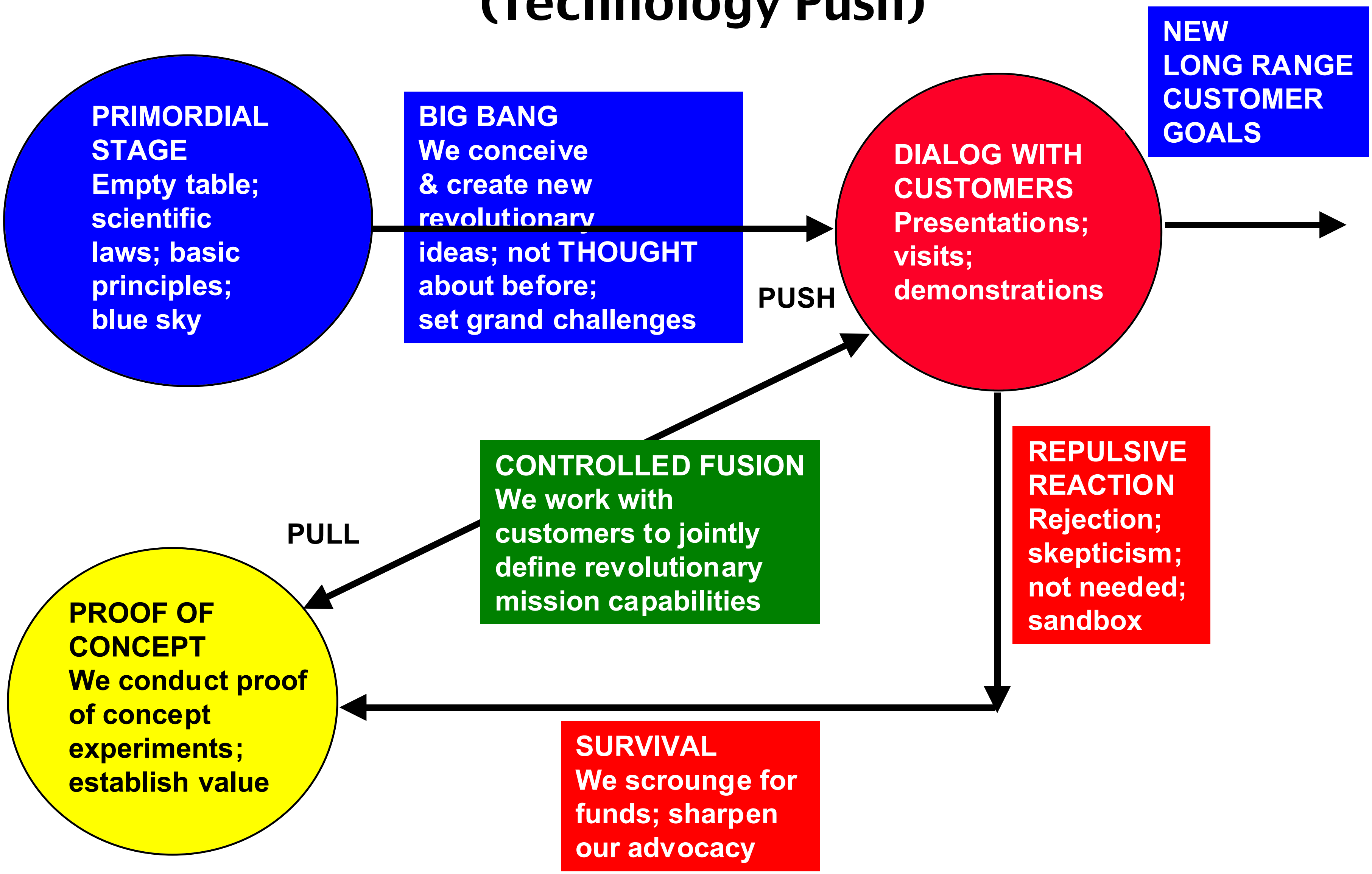
•***PUSH TECHNOLOGIES: Cause the Enterprises to rewrite, improve and expand their Strategic Plans***

- •Technologies that the Enterprises have not yet "bought into"
- •For years, Space Science resisted the use of rovers, but in the mid 1980s, it accepted the large expensive "Mars Rover Sample Return" (MRSR)
- •At that time, Space Science resisted the idea of small rovers, but later, based on UPN 632 research, developed the confidence to make small rovers a central part of their Strategic Plan

•***PULL TECHNOLOGIES: Enable existing Enterprise Strategic Plans***

- •Technologies that the Enterprises have accepted, but that do not yet exist
- •Many visions in the current Enterprise Strategic Plans are wonderfully revolutionary, and many of them were introduced by UPN 632

We Also Create Our Own Revolutionary Challenges and Work with Customers to Create New Long Range Goals (Technology Push)



Revolutionary Technology Enables New Revolutionary Missions

Technology Push Area (Examples)	Enabling Technologies	New Types of Missions Enabled
Ultra Lightweight Structures	Deployable structures; inflatables; ultra-high-precision thermal & vibration control	Next generation telescopes; large antenna systems
Distributed Spacecraft	Formation flying; relative navigation & control; precision sensing	Coordinated spacecraft networks for science, communications & navigation; interferometry missions
Robotic Outposts & Robot/Human Teams (New 00/01)	Collective autonomy; heavy duty robot work skills; robotic repair systems; multi-robot coordination	Human-precursor robotic missions; infrastructure deployment; global mobility & coverage; high-resolution in-situ surveys; high-risk operations
Micro/Nano Spacecraft	Micro electronic systems; integrated micro electronic & structural systems; micro propulsion devices	100-spacecraft SEU mission to map the magnetosphere; spacecraft constellations
All-Hazard Vehicle Safety Systems (New 00/01)	Precision landing & hazard avoidance systems; autonomous fault-protection & error recovery software; opportunistic adaptation systems	Multi-vehicle surface rendezvous; deliver assets at prior landing sites; high-risk (e.g. cliff descent) exploration missions

Enterprises

TECHNOLOGICAL SUCCESS STORY	HEDS APPLICABILITY	EARTH SCIENCE APPLICABILITY	SPACE SCIENCE APPLICABILITY
Sojourner & Robotic Sample Return Rovers	Surface Vehicle Mobility; Robotic Assistance to EVA		Wide Area Science; Robotic Outposts;
Ka Band Communications		SATCPOM Industry & Commercial Technology	Deep Space Communications
DS-1 Remote Agent Experiment	Space Vehicle Autonomous Maneuvering	Minimal Maintenance Earth-Orbiting Systems	Deep Space On-Board Navigation
Formation Flying Control Systems	Autonomous Rendezvous Systems	Earth Orbiting Constellations	Precision Telescope Arrays
Cloud Radar ; Weather Station; < mm Wave Detectors & MOMED Mixer		Enable O3 CloudSat Mission; atmosphere OH detectors	Planetary Atmosphere & Weather Surveys
NSTAR Ion Engine & SCARLET PV Array	Ion Propulsion in HEDS Roadmap	Up to 10 KW Applicable to Earth Orbit	Continuous Thrust Deep Space Missions
Hockey Puck Sized Magnetometer Spacecraft		Spacecraft Constellations	>100 S/C Constellations
Precision Deployable & Inflatable Structures		Inflatable Shields for Large Apertures	High-Precision Telescopes

CETDP PRODUCTS FOR THE HEDS ENTERPRISE (1 of 2 Charts)

	H1: ROBUST HUMAN EXPLORATION BEYOND LEO	H2: AUTONOMOUS OPERATIONS	H3: COMMERCIAL DEVELOPMENT OF SPACE	H4: EXTEND SCIENTIFIC DISCOVERY	H5: PERMANENT HUMAN PRESENCE IN SPACE
Atmospheric and In-Space Operations	Robotic control for exploration (crew assist simultaneous dual arm, fingered manipulator systems; robot/human interact	Aeroshells/brakes materials, testing and analysis; 3D automated rendezvous & docking		Advanced thermal protection systems analysis, materials selection, test	Autonomous, precision landing; passive and active beacon emplacement for navigation
Breakthrough Sensor Technology					
Distributed Spacecraft	Formation control for aerocapture, aeroentry, precision landing, and autonomous rendezvous & docking	Adaptive reasoning for cognitive systems control; advanced guidance, navigation and control systems for multiple spacecraft	Formation control systems, tools and testbeds		Autonomous and semi-autonomous systems for in-space formation control
High-Rate Data Delivery	Wireless nets and multi-access strategies and protocols for multiple spacecraft in proximity	Phased Array antennas; high power amplifiers; real-time telescience & telepresence;		Space internet RF communications and network modules; autonomous traking ground terminals	
Micro/Nano Spacecraft	Micro-electronics & GNC sensors; ultra-low-power digital circuits;	Radiation tolerance and design; micro-mechanical devices	Small, light,l0w-power fields and particles sensors; micro-propulsion devices	Integrated micro-power sources; advanced thermal control; extreme environment electronics (e.g. low temperature & high temperature)	Integrated micro-communication systems (short range); smart microstructures

CETDP PRODUCTS FOR THE HEDS ENTERPRISE (2 of 2 Charts)

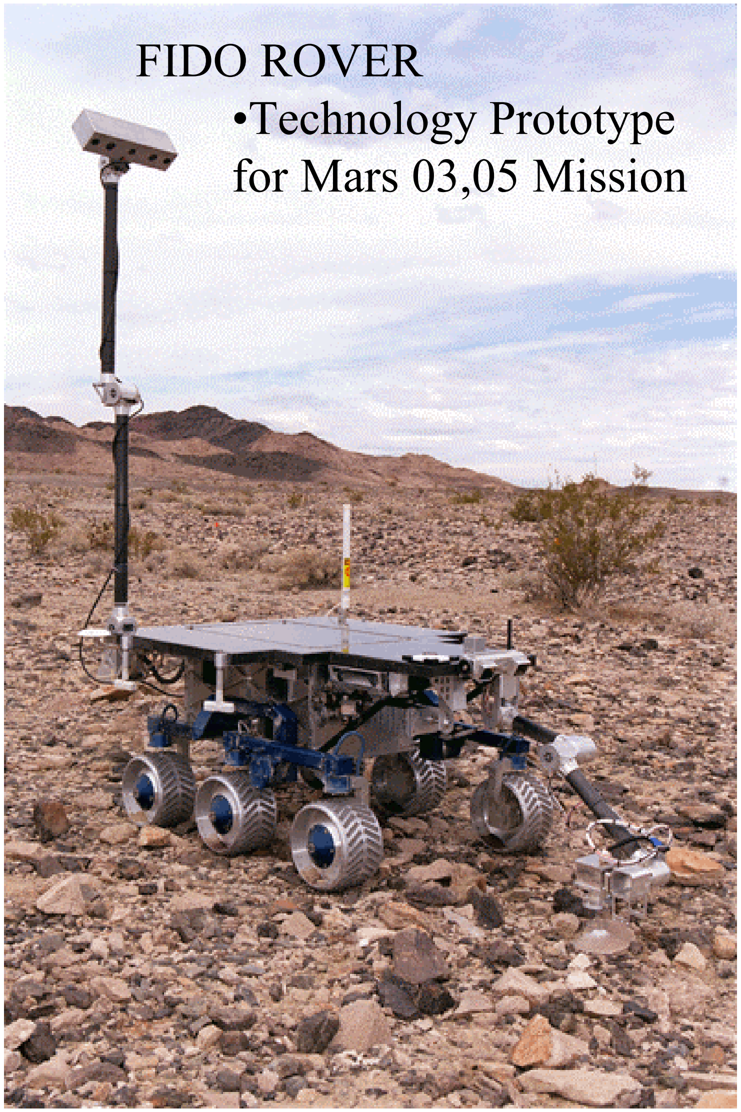
	H1: ROBUST HUMAN EXPLORATION BEYOND LEO	H2: AUTONOMOUS OPERATIONS	H3: COMMERCIAL DEVELOPMENT OF SPACE	H4: EXTEND SCIENTIFIC DISCOVERY	H5: PERMANENT HUMAN PRESENCE IN SPACE
Next Generation Infrastructure	Infrastructure for analytical simulations of in-space human operations	Human Operations Cost Analysis	Infrastructure to analytically optimize human operations and reduce risk	Analytical simulations of science discovery to select discovery options	Human operations analysis; cost and risk optimization analysis
Power & On-Board Propulsion (Architectural advances in the following synergistic technologies):	Advanced high performance electric propulsion /power; surface and rover power systems; advanced energy conversion	Micro-propulsion systems; PPT's with Power	Cheaper, longer lived power generation and storage systems; advance PMAD	Ultra-lightweight power	High efficiency power generation and energy storage systems; stationary and mobile power systems
Surface Systems	Autonomous surface vehicles; robotic assistance to EVA	Integrated human/robot operations; robotic outposts		High-risk access robotic systems; sample handling, preparation, and curation robotic systems	Robotic assistance to EVA
Thinking Space Systems					
Ultralight Structures & Space Observatories			Thermal protection materials for aerocapture and aeroentry systems		Lightweight and high strength structural materials; radiation shielding materials, inflatable habitats; lightweight solar arrays

Surface Systems Thrust Success Story

Rover Technology Enables Sample Return Missions

•Rover and science payload technology for NASA 03,05 Mars Sample Return Missions
•Multiple Science Instruments (Raman, Mossbauer, Mini-Corer, etc.)
•Complete science acquisition and return sequence field simulations (April 1999)
•Built on earlier success of Sojourner (97) Rover and Mars Volatiles and Climate Surveyor (MVACS 99) robot arm technology

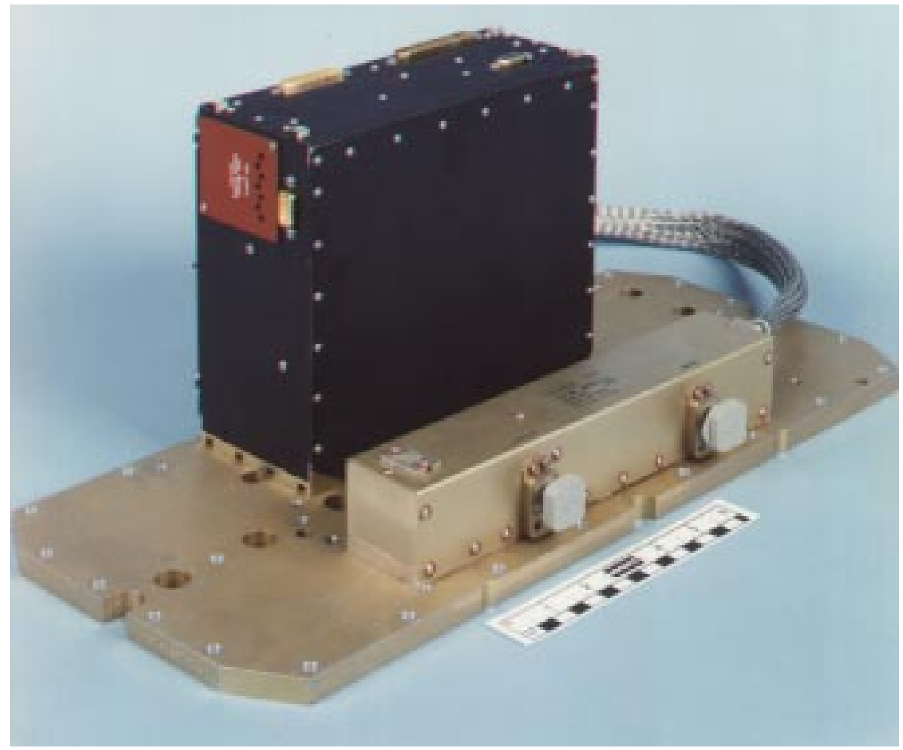
Surface Mobility, Navigation, Sampling, and Rover Operations Technologies demonstrated in Sample Return Missions are Precursors to Subsequent HEDS Exploration Missions



Recent Success Story for High Rate Data Delivery Thrust

CETDP Technology Enabled Cassini Mission Experiment

- First Ka-band TWTA for Deep Space Mission
- Enables Cassini Ka-band gravity wave experiment
- Technology doubles efficiency of 32 GHz TWTA
- Two flight TWT's and EM TWTA produced
- GRC Impact
  - Designed TWT collector and helix circuit
  - Textured collector surfaces with unique GRC process



10-Watt, 32-GHz TWTA

Remote Agent AI Software Flies on New Millennium DS-1

•REMOTE AGENT software experiment aboard the Deep Space 1 spacecraft shows how robotic explorers of the 21st century can be built to be less costly, more capable and more independent from ground control.

•Planner and Scheduler (PS)--produces flexible plans, specifying the basic activities that must take place in order to accomplish the mission goals.
•Smart Executive (EXEC)--carries out the planned activities.
•Mode Identification and Recovery (MIR)--monitors the health of the spacecraft and attempts to correct any problems that occur.

•REMOTE AGENT successfully controlled the spacecraft for a two day period, planning and executing its actions, and recovering from simulated faults that were injected by the ground team.

CETDP PRODUCTS FOR THE EARTH SCIENCE ENTERPRISE (1 of 2 Charts)

	E1: ADVANCED SENSORS	E2: SENSOR WEBS	E3: ACCESS TO KNOWLEDGE	E4: INFORMATION SYNTHESIS
Atmospheric & In-Space Operations				
Breakthrough Sensor Technology				
Distributed Spacecraft		Autonomous navigation sensing and pointing of spacecraft fleets; mission and design analysis tools and testbeds		On-board autonomous control systems; collaborative autonomous systems; distributed optimization and control tools
High-Rate Data Delivery	Optical communication systems and high-risk detectors & lasers; high-risk microwave components	Inter-spacecraft communications modules & networks; integrated navigation and communication systems	Space net protocols; reliable multicasting; propagation models, high rate modulators; radiation hardened transceivers	
Micro/Nano Spacecraft	Micro-electronics & GNC sensors; ultra-low-power digital circuits; radiation tolerance and design; micro-mechanical devices	Small, light,l0w-power fields and particles sensors; micro-propulsion devices	Integrated micro-power sources; advanced thermal control; extreme environment electronics (e.g. low temperature & high temperature)	Integrated micro-communication systems (short range); smart microstructures

CETDP PRODUCTS FOR THE EARTH SCIENCE ENTERPRISE (2 of 2 Charts)

	E1: ADVANCED SENSORS	E2: SENSOR WEBS	E3: ACCESS TO KNOWLEDGE	E4: INFORMATION SYNTHESIS
Next Generation Infrastructure	Infrastructure for analytical simulations of earth observing systems performance, cost and risk	Tools for rapid performance analysis of what if scenarios to assess responsiveness of proposed Sensor Web designs	Infrastructure for efficient data access to and from geographically distributed sites	Infrastructure for information synthesis and assessment of information synthesis through ISE testbeds
Power & On-Board Propulsion (Architectural advances in the following synergistic technologies):	Advanced bus technologies and electric propulsion; 50% payload increase; reduced cost, increased power, 2X life	Precision low-impulse thrusters; "Green" monoprops, 350 ISP bi-props; micro-thrusters	ATOX Protective coatings	"Cold Electronics"
Surface Systems		3-media (surface, sub-subsurface, aerial) multi-robot arrays		
Thinking Space Systems				
Ultralight Structures & Space Observatories	Submillimeters and far IR optics; inflatable antennas for microwave radiometers and synthetic aperture radar; deployable lidar telescopes; conductive cooling for laser diodes; lightweight instrument optics			

Formation Flying Autonomous Navigation and Control
EO-1 Flight Experiment

NMP Autonomy IPDT

- EO-1 flight experiment with Landsat-7 in 1999

Co-funded by NASA Code S Cross Enterprise Technology Development Program

- Increased level of autonomy through expert systems/AI technologies

Goal

- Improve space science data return through simultaneous observations from multiple satellites

Objectives

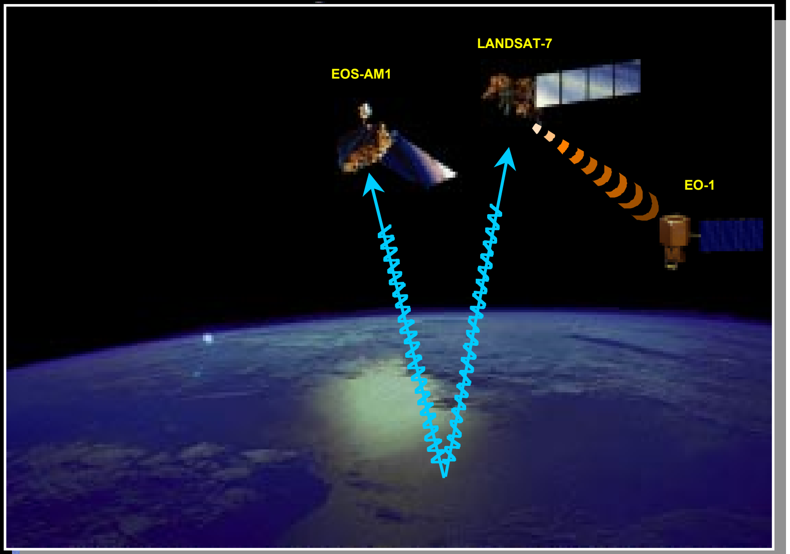
- Demonstrate the capability of gathering collaborative science data from multiple spacecraft whose navigation and orbit control functions are executed cooperatively and autonomously as part of a coordinated network

Benefits--Technology will enable

- Synchronous science measurements on multiple spacecraft
- Weather and land-imaging collection 8-16 times faster than current Lansat or TIROS satellites
- Autonomous operations will allow large numbers of satellites to fly with minimum ground support

Partners: GSFC, JPL, Stanford University, AI Solutions, Hammers Company

Distributed Spacecraft Thrust



EO-1 Formation Flying Experiment

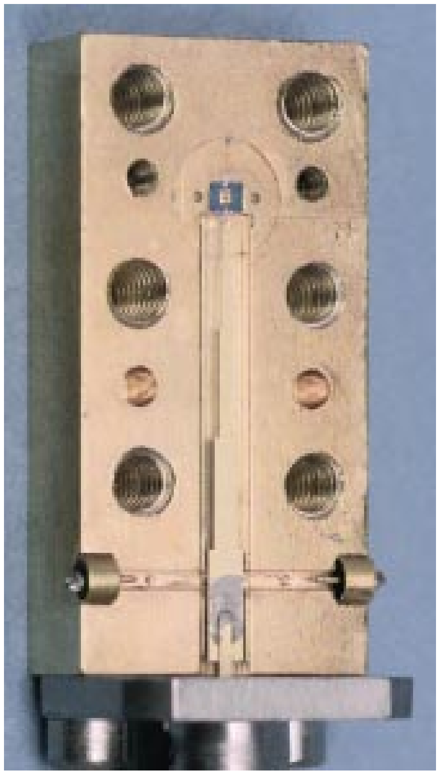
- **Onboard autonomous maneuver control to maintain EO-1/LS-7 formation**
- **EOS-AM1 Flies nominal mission**
- **Landsat-7 Flies in a constellation with EOS-AM1**

OES selects CloudSAT mission to fly in 2003

- The enabling technology for CloudSat mission - a 94GHz high power transmitter - developed under 632 program (1993 - 1996)
  - CSMT Sensor Technology Program jointly funded technology development of the Airborne Cloud Radar with NASA Code Y Atmospheric Dynamics & Remote Sensing Branch (R. Kakar)
  - Collaboration: University of Mass, Colorado State University, JPL Lead Fuk Li
- 1996
  - Continued Joint Development of the Cloud Radar with Code Y Cloud & Radiation Program (Bob Curran)
- April 1999
  - NASA Awarded CLOUDSAT Mission to JPL with Colorado State University as PI ($110 M)
  - Collaborator: Canadian Space Agency, USAF; (~$25M Commitment); Major Industrial Partner – Ball Aerospace

Submillimeter-Wave Radiometer Components MOMED Mixer

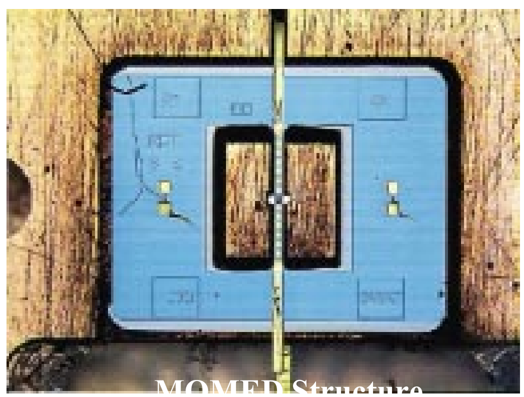
<u>OBJECTIVE:</u> Developed all-planar GaAs-based mixer for use at 2.5 THz (118 microns)
<u>CUSTOMER:</u> Earth Observing System Microwave Limb Sounder - 2.5 THz radiometer for measurement of atmospheric OH



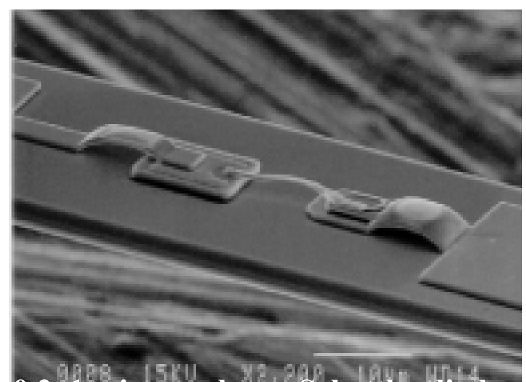
2.5 THz Mixer Block

<u>ACCOMPLISHMENTS:</u>

- **Invented a novel MEMS-like circuit composed totally of GaAs & incorporating state-of-the-art planar submillimeter-wave devices & filters**
- **Device is now baselined for EOS-MLS, replacing less reliable "point-contact" structure with robust space-qualifiable component**
- **RF performance is competitive with any semicond. radiometer at this frequency**
- **New MOMED technology enables other RF & electro-mechanical applications not realizable with traditional silicon MEMS structures**



MOMED Structure



0.2x1 micron planar Schottky diode

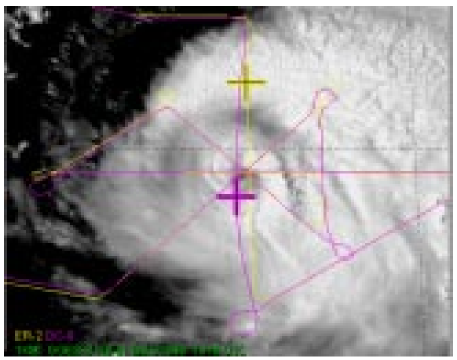
<u>Performance at 2.5 THz:Trec=16,500K DSB; Tmixer<9000K; LO Power Required: <3mW!</u>

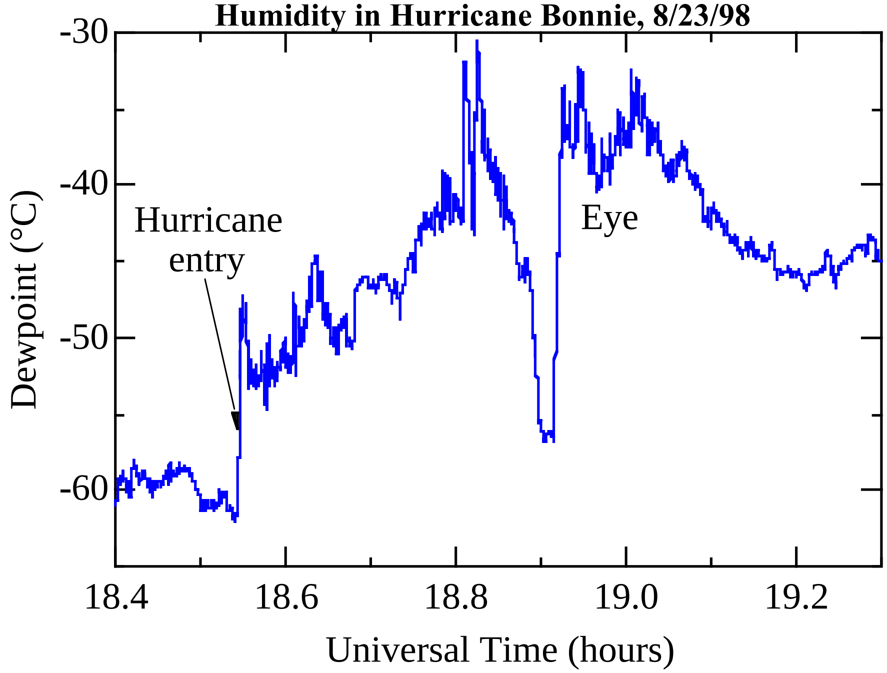
Flight Validation of Micro Weather Station

Micro Weather Station Objective: Develop unique microsensors for accurate in situ monitoring of weather in Earth and planetary atmospheres.

- Flight validated a miniaturized SAW hygrometer on the NASA DC8.
- Generated high-resolution humidity data in Atlantic hurricanes (Third Convection & Moisture Exp't.)
- Sponsor is evaluating possible use as a national standard for in situ atmospheric humidity.

Hurricane Bonnie, 8/23/98
Satellite image with flight tracks





SAW Hygrometer data, CAMEX-3

CETDP PRODUCTS FOR THE SPACE SCIENCE ENTERPRISE (1 of 2 Charts)

	S1: ORIGINS	S2: STRUCTURE & EVOLUTION OF THE UNIVERSE	S3: SOLAR SYSTEM EXPLORATION	S4: SUN-EARTH CONNECTION
Atmospheric & In-Space Operations			Autonomous mini-flyers for atmospheric condition characterization for other planets	
Breakthrough Sensor Technology				
Distributed Spacecraft	Formation control for telescopes; communications; computer and data management	High-precision formation flying; nanometer spacecraft control		Autonomous spacecraft systems; constellations; formation control systems
High-Rate Data Delivery		Miniaturized RF communications modules; high-rate turbo codes;	In-situ communication systems for landers and rovers; in-situ protocols; reconfigurable networks	
Micro/Nano Spacecraft	Micro-electronics & GNC sensors; ultra-low-power digital circuits; radiation tolerance and design; micro-mechanical devices	Small, light,l0w-power fields and particles sensors; micro-propulsion devices	Integrated micro-power sources; advanced thermal control; extreme environment electronics (e.g. low temperature & high temperature)	Integrated micro-communication systems (short range); smart microstructures

CETDP PRODUCTS FOR THE SPACE SCIENCE ENTERPRISE (2 of 2 Charts)

	S1: ORIGINS	S2: STRUCTURE & EVOLUTION OF THE UNIVERSE	S3: SOLAR SYSTEM EXPLORATION	S4: SUN-EARTH CONNECTION
Next Generation Infrastructure	Infrastructure for analytical simulations of optical performance, cost and risk	Infrastructure for analytical simulations for deploying precision flying systems	Infrastructure for analytical simulations of autonomous robotic operations	Performance simulations and risk analysis of solar sails and miniature spacecraft
Power & On-Board Propulsion	Precision micro-newton thrusters, accompanying power systems – ultra-lightweight & long-lived	Micronewton thrusters, pulsed plasma thrusters – ultra-light long lived power systems	Advanced chemical and SEP propulsion systems, robotic power, mobile power; integrated batteries, PV arrays, vehicle power systems; integrated power and SEP systems	Advanced spacecraft power and on-board propulsion systems; integrated thin film power systems; microthrusters; pulsed plasma thrusters and power for spacecraft constellations
Surface Systems			Surface & sub-surface vehicles; multi-robot teams for exploration; high-risk access systems; robotic sampling systems; deep subsurface systems; robotic outposts	
Thinking Space Systems				
Ultralight Structures & Space Observatories	Large cryogenic apertures, diffraction limited optics, active wave-front control, vibration isolation, control of micro-dynamics	Large inflatable antennas, X-ray optics, large Fresnel lenses, thermal isolation, control of spacecraft charging	Solar sails, solar reflectors/concentratorslightweight solar arrays, large inflatable antennas, advanced thermal control systems	Solar sails, long-lived spacecraft systems

Solar Electric Propulsion Flies on New Millennium DS-1 Mission

Operation of 2.6 KWe ion engine (NSTAR) in space with advanced solar concentration PV array (SCARLET)

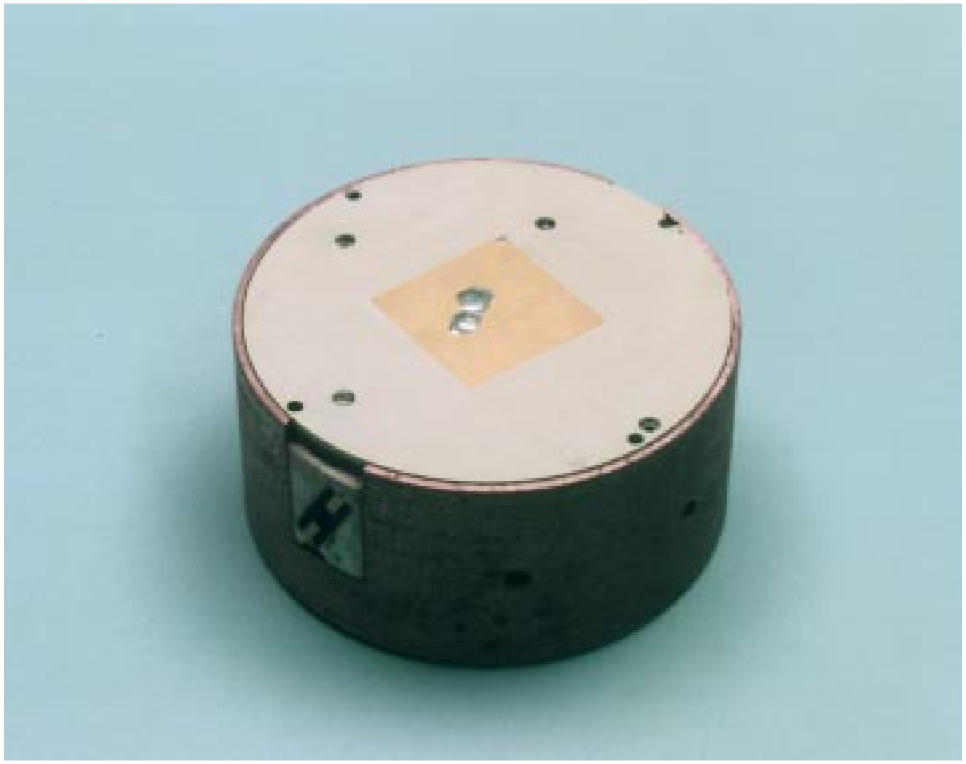
- First NASA use of SEP in mission
  - Culmination of years of research
- First application of solar concentrator array
  - Highest efficiency MBG.PV cells ever flown (23%)
  - Increased w/Kg, low cost
- Opens the door for widespread use of electric propulsion
  - Increased mobility
  - Reduced trip times
  - Smaller launch vehicles

SCARLET

NSTAR

Successful Flight of Three Free-Flying Magnetometers Paves Way for Future Mapping of Magnetosphere with 100-Spacecraft Constellation

- **Free-Flying Magnetometer flight demonstrated ability to make simultaneous magnetosphere measurements from multiple spacecraft constellation in CY'98**
  - Four "hockey puck" sized magnetometer spacecraft
  - Magnetically "clean"
  - Enstrophy Mission, joint with UNH and Cornell, measured Curl-H on short spatial scales
  - Sub-orbital trajectory used BB-X rocket launched from Poker Flats, AK
- **Proposed for ST-5 a part of demonstration of other needed technological capabiities to accomplish a 100-spacecraft constellation**

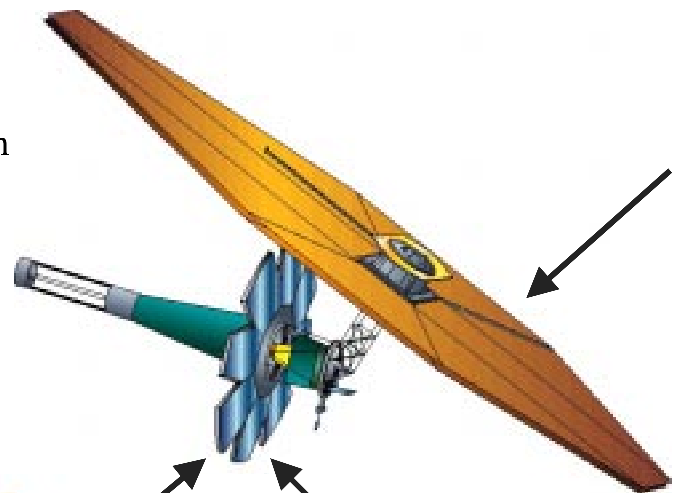


Enabling precursor to 100-spacecraft SEU mission to map the magnetosphere

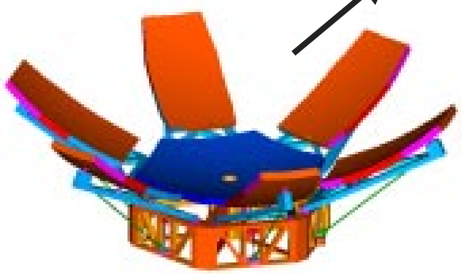
Ultra-Lightweight Structures and Space Observatories Thrust Success Story

CETDP Revolutionary Technology Has Enabled Revolutionary Missions

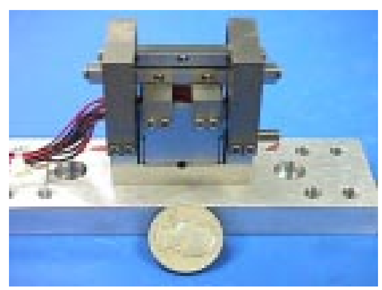
The Next Generation Space Telescope (NGST) will study the origins of galaxies at the edge of the universe. NGST will have 2x greater resolution than the Hubble Space Telescope at infrared wavelengths, and cost 1/4 as much.



Inflatable sunshield developed by CETDP will passively cool telescope to cryogenic temperatures. Inflatable structure enables 10x reduction in launch volume and 2x reduction in sunshield weight. Shown is a 1/2-scale model of the inflatable NGST sunshield.



Precision deployable telescope technology developed by CETDP will enable large apertures to be flown on smaller, lower-cost launch vehicles. Deployable primary mirror enables 3x increase in aperture size. Shown is one petal of a deployable reflector testbed with sub-micron deployment precision.



Cryogenic actuators developed by CETDP will control shape of NGST primary mirror to nanometer precision. Actuators will operate at 30 ^{o}K. Shown is prototype piezoceramic linear actuator.

Surface Systems Thrust Success Story

The Giant Rover that Could

Key Technologies

•Autonomous hazard avoidance & navigation
•6-Wheel rocker-bogie mechanism
• APXS instrument deployment
•Miniaturized rover system

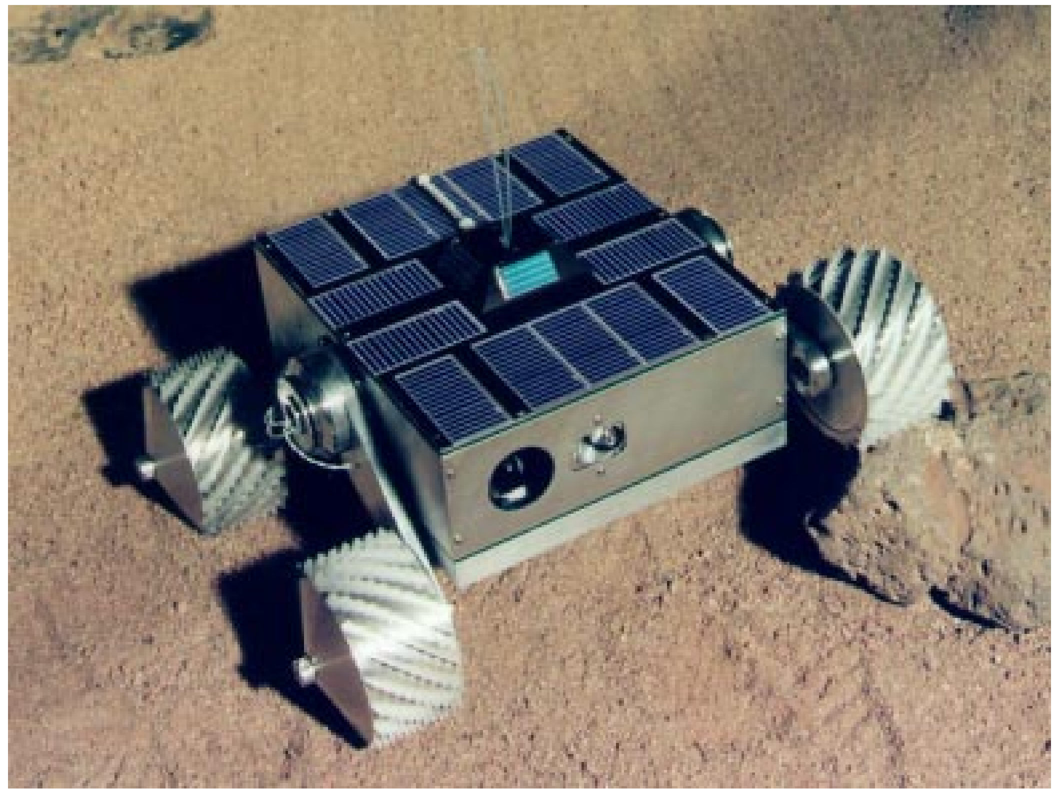
In-Space Robotics Performance

•~100 m traverse
•~15 APXS measurements
•~20 Soil mechanics measurements
•Deployment Maneuver from Lander

Surface Systems Thrust Success Story

MUSES CN ~1 kg Rover Technology

- NASA Flight Experiment in Muses C Asteroid Mission (02)
- Self-Righting Mechanism
- Embedded Point Spectrometer



632 R & D Critical to Nurture and Unfold the Success Stories

(Example: Technology Leading to Sojourner and Successor Rovers)

- DARK AGES (1977-1992)
  - After Viking, NASA support for rover technologies vanishes and is kept there by powerful forces
  - Small nucleus of “true believers” at JPL and NASA HDQS sustain the spirit of rover research (Wilcox, Ruoff, Montemerlo, Lavery, Weisbin, etc.)
  - 632 funds are only lifeline; no other NASA funds; active discouragement from others
- RENAISSANCE (1990-1994):
  - Rover technology sufficiently mature to interest planetary scientists (M. Golombek)
  - Proof-of-concept demonstration that a small rover could do useful science (J. Cutts, L. Lane, C. R. Weisbin, etc.)
  - Sojourner approved as a technology flight experiment (H. Stone, H. Eisen, D. Shirley, etc.)
- ENLIGHTENMENT (1993-1999)
  - Community of planetary scientists recognize value of rover technology and become advocates (Squyres, Arvidson, Carr, McCleese, Murray, etc.)
  - Athena rover and science payload are selected for Mars Sample Return Missions
  - Sojourner roams the Martian surface
  - **Rover technology now indispensable for Mars surface exploration**

Could the Basic Technology Enabling Sojourner Have Been Developed without 632-Type Support?

- Would the rover technology have survived the Dark Ages (1977-1992)?
  - No; no mission customer interest; no perceived need; active discouragement and attempts to eradicate it in its infancy
  - Technology was adopted first by scientist community; mission-driven technologists acceptance came later
- Could it have been done by a focused technology program?
  - Possibly, but very unlikely
  - How would the “focus” have been determined and by whom? Time horizon?
  - Core technologists or mission-driven technologists? Medieval or renaissance?
  - Would technological opportunities have been recognized and nurtured?
- Does history repeat itself?
  - At the time of its greatest mission success, rover technology support by focused programs is in jeopardy due to “more critical” mission drivers
  - 632-type R & D comes to the rescue one more time; can enable missions that have never been done, or have even been conceived, before
  - 632 track record for supporting technologies through the “Dark Ages” is unmatched

Political Pressures on 632 Occur Every Year: Only the Details change

(~1985) Stop doing any technology for Shuttle because it is a fully operational/mature program
(~1985) Focus most of space technology on Space Station to help make it happen
(~1989) Focus on Human Exploration Initiative (HEI)to help sell the program (Bush administration)
(~1990) The next year: drop all mention of HEI from the program.
(~1991) Plan program based on Norm Augustine's predicted tripling of the NASA technology budget
(early 80s, and ~1988) Separate the R&T Base from the Focussed Technology
(~1985, and ~1990) Integrate the R&T Base and Focussed Technology
(~1990) Separate Space Transportation technology out so we can sell what became the RLV program
(~199?) Space Station technology no longer needed because it is under Boeing.
(~1992) Rebalance to 80%Push, 20%Pull (Pete Peterson)
(~1992) Downsize Headquarters, Use TQM (Goldin)
(~) Do not do industry welfare (Bush)
(~1992) Focus on commercialization (Clinton Gore)
- (~1992) NASA Technology Transfer Blue Team (Creedon)

(1993) Push from Dan/Sam to rebalance to 80%Pull, 20%Push (If you are not relevant, you are gone)
(~1994) Reduce/eliminate technology program money going to the User Centers (JSC/KSC/MSFC)
(~1995) The Zero Based Review says reduce numbers of Centers working in each technical area
(1997) 7120.5A
(1997) Congressional language calling for "broadly announced, peer reviewed" technology.
(1998) OCT pressure to rebalance to 100%Push, 0%Pull, (in other words, again separate R&T Base from Focussed (now called Enterprise-Unique)
(1999) plan to double size of "Push" program in 2000
and to massively increase ISE & Intelligent Systems by using "Functional Initiatives"
(2000) OCT to reverse Congressional mandate for "broadly announced, peer reviewed technology"
- consideration given to splitting up Cross Enterprise Technology, or to moving it to different Enterprise

The CETDP Technological Dream is Alive

- Research responds to noble and inspirational goals
  - Zero-uplink robotic systems
  - Autonomous global circumnavigation of planetary surfaces; deep sub-surface steering and navigation
  - Robot nomads and caravans on planetary deserts
  - Sense & analyze every ion in the universe
  - Robotic work crews
  - Air/surface/sub-surface robot formations
  - Self-repair and self-reproducing systems
  - Human/robot teams
  - Etc.

Will Our Dreams Materialize?

- Majestic Challenges Facing Us
  - WE picked these challenges “not because they are easy but because they are hard”
  - As we take the long view, WE may never get there
  - Some of the challenges may take generations to overcome
  - Autonomy is easy to conceive but difficult to implement
  - For the foreseeable future, there will be fundamental limits in ways to interact with the environment
  - Human like dexterity, touch, and intelligence are yet to be matched
  - Much revolutionary technology is in its infancy (e.g. Sojourner)
  - Stakeholders (sponsors, public, everyone) may lose patience and cut budgets